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Developing an oasis-based irrigation management tool for a large semi-arid mountainous catchment in Morocco

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Abstract: This study is concerned with the management of water resources and development of a DSS (Decision Support System) in MMS (Modular Modelling System) for the semi-arid, mountainous Drâa catchment in SE Morocco. The catchment relies heavily on oasis irrigation in three different geographical units. These include firstly, the High Atlas mountains, secondly, the basin of Ouarzazate above the Mansour Eddahbi dam reservoir and thirdly the ancient date palmeries below the reservoir. In 1972 the dam was put into operation for hydroelectricity and irrigation. Following decades of drought the dam's main function nowadays is irrigation. A DSS requires an efficient hydro-meteorological monitoring system including the infill levels of the reservoir and the water use upstream of the reservoir. It also involves close collaborative feedback between the developers and the water planning authorities and local end-users. In the mountains surface water is still more or less an unlimited resource but in the forelands it is very limited for irrigation. Uncontrolled spread of mechanised pumping is seriously straining the groundwater resources. In terms of potential end-users, farmers in the mountain areas will be unable to implement a DSS due to high illiteracy. However, the interest will be high for centralized agricultural and regional hydrological organisations involved in water planning such as the ORMVAO (Organisation pour la Mise en Valeur Agricole de Ouarzazate), farming organisations and the ABH (Agence du Bassin Hydraulique) du Souss-Massa-Drâa.

Keywords: Oasis; Semi-arid mountains; Draa catchment; Decision Support System, Reservoir

1. INTRODUCTION

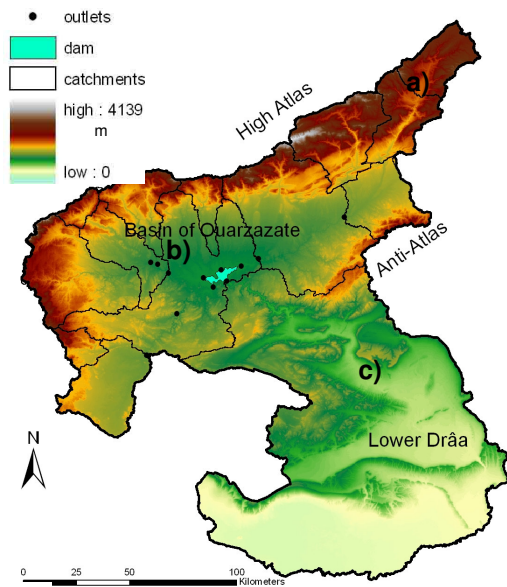
The Drâa belongs to the 10 most arid catchments of the world [Ravenga et al 1998] ranging from the High Atlas Mountains to the basin of Ouarzazate and the extensive irrigated oases south of the Mansour Eddahbi dam reservoir. Major hydrological issues include high climatic variability, erratic river flow, decreasing capacity of the main regional dam [de Jong et al 2005, Lahlou 1988], falling water tables, high evapotranspiration rates [Hübener et al 2004] and increasing salinity in irrigation areas whereas policy and legislative issues include pumping and control of lâchés (diversion sluices). Within the next 30 years a 10% decrease in precipitation in West Africa, could cause a 50% decrease in surface discharge [de Wit and Stankiewicz, 2006]. This requires an excellent water management tool that takes into account the above issues. Water management refers to both water service providers managing water resources on a regional scale and farmers managing water on a farm scale.

Several organisations are at present involved in watershed planning of the basin, including ABH (Agence du Bassin Hydraulique du Souss-Massa-Drâa), Agadir [Ministère de l'Équipement, Direction Générale de l'Hydraulique 2002], IMPETUS [de Jong et al 2004], ORMVAO,

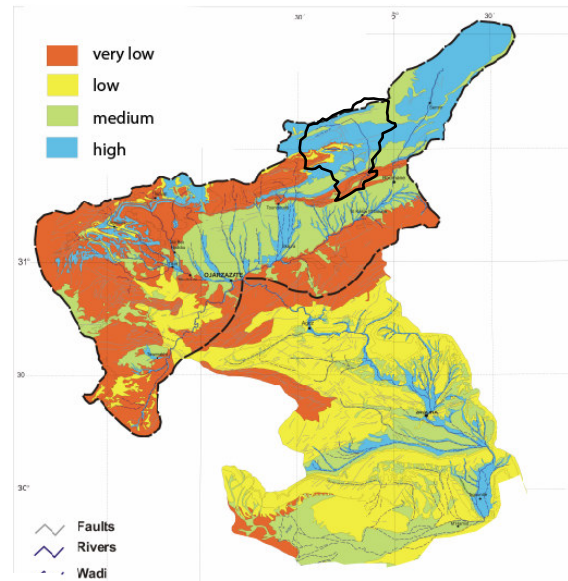
Ouarzazate, SIGMADRAA [Aghezzaf et al 1998] and UNESCO-HELP [UNESCO-HELP 2003]. At the national scale there is the PNE (National Water Plan) and at the regional scale, it is the PDAIRE (Director Plan for Integrated Water Resources Management). It describes the relation between water need and resources and includes an Action Plan up to the year 2020 on the basis of a business plan. In future, a special Agency for the Protection of Drâa Oases will be created with strong support by the Ministry for Water and Environment. Another focus is on progressive irrigation technology for economisation of water use and regulation of groundwater pumping.

Planning tools have to consider that water resource prediction is unreliable since most rivers feeding the reservoir are ephemeral and derive their flow from sporadic and discontinuous snow and rainfall events from the High Atlas mountains [Schulz and de Jong 2004] and data on human water abstraction is difficult to obtain. In addition, increased mechanisation of pumping is causing over-exploitation of groundwater reservoirs which is also common north of the High Atlas [Abourida et al 2005]. Traditionally water resources were used for sustainable purposes only and could be managed on a non-technical basis. Now that they are exploited in large amounts for irrigation of market products the pressure on water resources is growing and management tools are essential. The

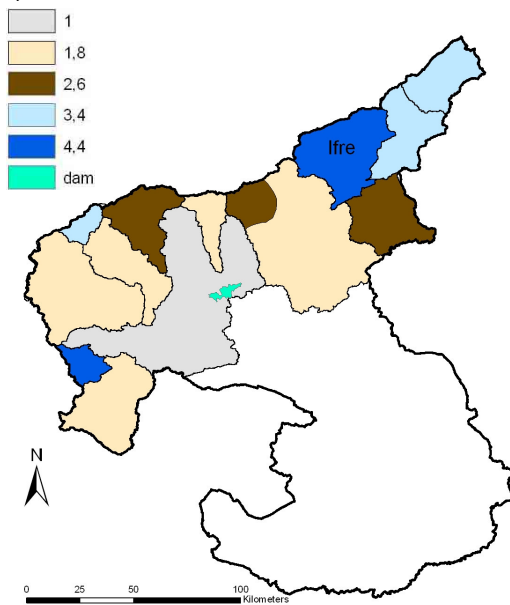
a) Digital Terrain Model



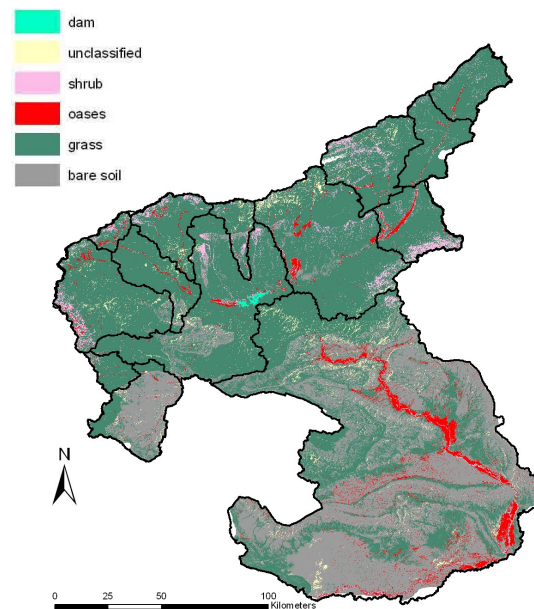
b) Groundwater availability



c) Specific discharge (l/s/km²)



d) Vegetation cover



e) Settlements and pumping wells

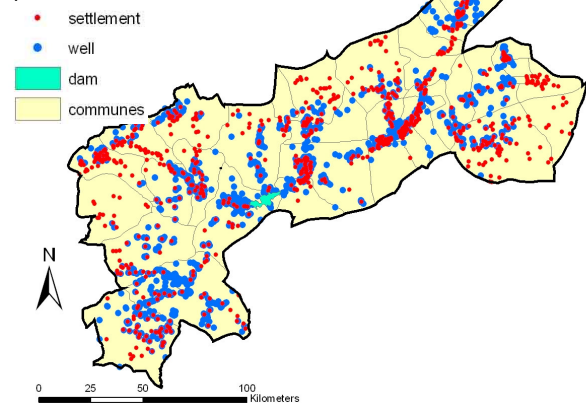


Figure 1 a) Delineation of subbasins on DEM, b) geological map of groundwater availability [Cappy], c) discharge per unit area (annual average) of subbasins, d) vegetation and irrigated oases [Poete & de Jong] and e) settlements and pumping wells in the Upper Drâa [after Ministère de l'Équipement, 2002].

implementation of a DSS for water management requires intensive involvement of stakeholders and end-users [Spiteri 2005] even though illiteracy has to be taken into account. Technically, the DSS requires a fundamental GIS and hydro-meteorological data base with a flexible hydrological open source modeling package, such as MMS at its centre [Mastin and Vaccaro, 2002] that is sensitive to global and climatic scenarios. A wide set of stakeholders is identified as end-users, since water use and management is a problem involving all disciplines and sectors of the society (e.g. household, tourism and irrigation).

2 DRÂA CATCHMENT

The Drâa catchment has an area of 34,609 km² with a minimum and maximum altitude of 450 and 4071 m respectively [de Jong et al 2005]. It is characterized by a semi-arid climate, dominated by dry summers and winters with erratic precipitation. The Drâa is influenced by the wintery, snow covered High Atlas mountains. The Mansour Eddahbi reservoir accumulates

different stream discharge emerging from the mountains (a), transiting the sedimentary basin of Ouarzazate (b) and is important for the extensive irrigated oases areas (c) downstream (Figure 1a, c & d). Irrigation is dependant both on surface discharge and groundwater reservoirs (Figure 1b&d) which marks the areas with settlement and pumping wells (Figure 1 e).

In total, 43,065 ha are irrigated in the catchment, with 180 and 213 million m³ of water used for irrigation in the upper and lower Drâa respectively [Ministère des Travaux Publics 1998, UNDP 1994]. Future water requirements in the lower Draa, with 6 major date palmeries, amount to 350 million m³. In the upper Drâa approximately 20% of irrigation water is extracted from groundwater and 80% from surface water. In the lower Drâa 70% of irrigation water is extracted from the Mansour Eddahbi dam reservoir, only 20 % is pumped from groundwater and 10 % originates from surface water (Figure 4 a and b). Groundwater availability is highly variable (Figure 1b). Whereas it is high in north-eastern parts of the catchment in the High Atlas at

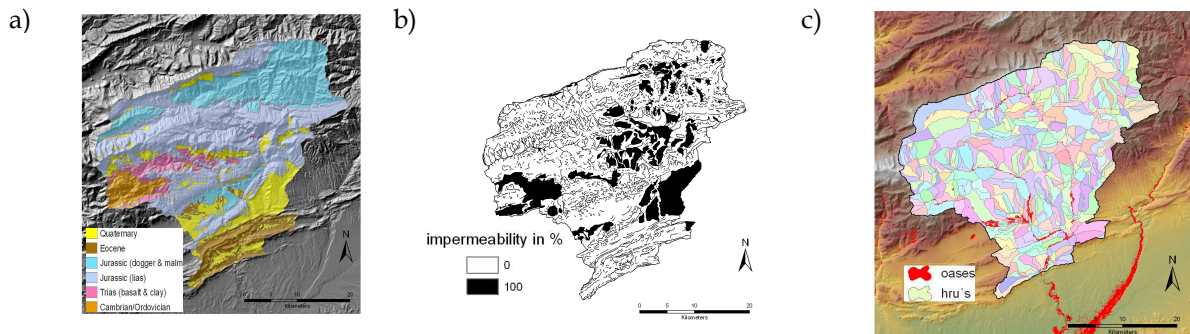


Figure 2 a) Geological background [Cappy & de Jong], b) permeability [de Jong] and c) distribution of oases and HRUs in the Ifre catchment [de Jong]

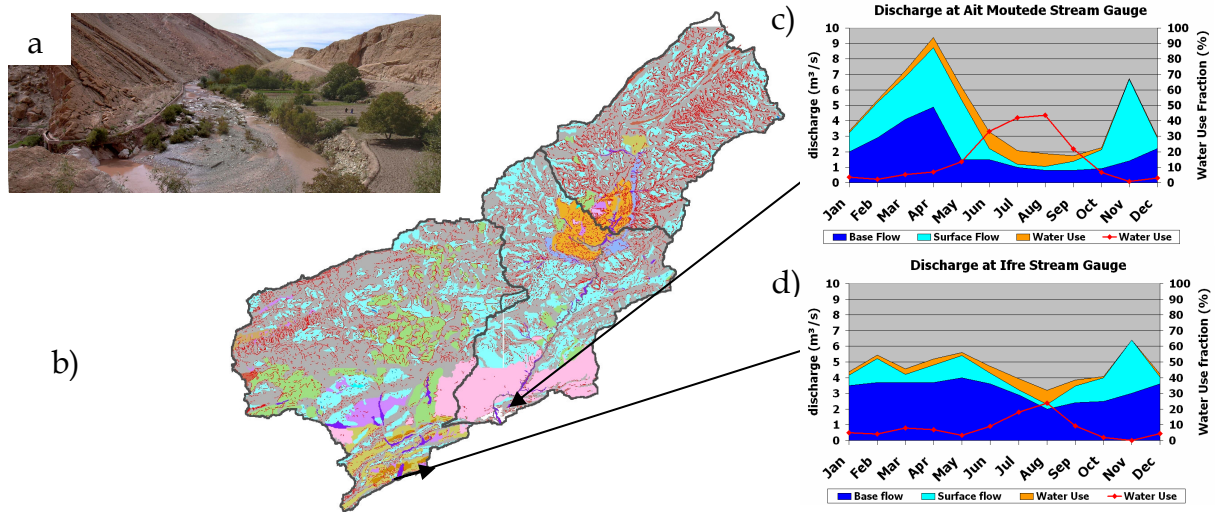


Figure 3 a) Example of oasis irrigation from nearby river [Photo: Schulz], b) geomorphological discretization of eastern High Atlas mountains [de Jong] and water extraction for irrigation from surface discharge at c) Ait Mouted and d) Ifre [after Youbi 1990].

altitudes above 1800 m, in the oases of Skoura north-east of Ouarzazate and in the entire southern oases zone of the River Drâa, it is very low in the Anti-Atlas and in the northwestern parts of the catchment. Water quantity does not correspond with quality however, so that the most important southern irrigated zones between Agdz and Mhamid have the poorest water quality due to high salinity. The same is true for the former Lac Iriqui, now a dessicated salt pan.

3 DECISION SUPPORT SYSTEM

The MMS (Modular Modeling System) [Leavesley et al 2002] forms a framework for the DSS of the Drâa. The types of models that will be required within this framework to address water management issues include a coupled surface water and groundwater model (GSFLOW), a snowmelt- and sublimation model, an erosion detachment and transport model (to calculate the siltation of the dam) and an irrigation model to address the basic hydrological needs. In addition, a set of tools to generate future climatic conditions and associated meteorological variables, both in the form of a weather generator, downscaling from atmospheric models and using historic data as an analog for the future is necessary.

3.1 GIS Pre-processor for DSS

A DSS requires a sound GIS data base. For this purpose the GIS-pre-processor of MMS was applied [Viger et al 1998]. In order to demonstrate the complexity of the physical setting of the Drâa, the mountainous Ifre catchment was selected. The geology (Figure 2a) and geomorphology (Figure 2 b & 3 b) determines permeability, which in turn influences whether surface or subsurface flow occurs (Figure 2c & 3 c and d). Where the valleys are sufficiently wide and enough flow can be concentrated or where good quality groundwater reservoirs are located near to the surface, oases areas are intensively irrigated (Figure 3 a), especially during the dry summers when up to 50% of river flow is extracted for irrigation (Figures 3 c and d). Even so, in mountainous catchments such as Ifre restricted by valley slopes, only 1% of the surface area can be irrigated. Hydrological Response Units (HRU)s are generated on the basis of the DEM with the GIS Weasel (Figure 2 c). The discretization of hydro-geomorphological units (Figure 3 b) for the mountainous regions is an important prerequisite for pervious-impervious zoning and for substituting soil information.

3.2 Hydro-meteorological and water abstraction monitoring for DSS

In addition to the GIS data base, a DSS requires both a hydrologically-based model, hydro-meteorological data as well as irrigation water abstraction data and a knowledge of the regulation of lâchés from the dam reservoir. In this case the management tool is based on MMS.

The Ifre station can be taken as a typical example for a mountain catchment with a high flow variability (Figure 3 d). Recorded maximum discharge reached 1400 m³/s in November 1965 and a minimum of 0.71 m³/s in July /August 1984 [Youbi 1990]. Both Youbi [1990] and our observations indicate that there is no straightforward correlation between precipitation and discharge. Only approximately 30% of the precipitation of the Ifre catchment actually reaches the stage recorder.

The data show that in the mountain regions, snow inputs dominate the river discharge and percentage irrigation is low, mainly due to confined land. However, in the basin of Ouarzazate surrounding the reservoir, snow inputs are low and percentage irrigation is high. Agricultural and population pressure on the land is much higher and although land itself is much less a limitation, water resources have to be carefully managed. Here, substantially more water (approx. 25%) is necessary than is available.

It is in these regions that a DSS has to be fully understood and implemented by the local authorities, farmers and irrigation units in order to ensure its sustainability. In contrast to the mountain regions, there is both pressure on surface water and groundwater reservoirs in regions (b) and (c) (see section 2 Draa catchment). Therefore, the local end-users have to be made aware, through educational and communication projects, of the vulnerability of water resources as effected by modern exploitation techniques such as pumping and lâchés. For this purpose, it is important to apply collaborative approaches i.e. collaborative identification of issues within an adaptive modelling strategy. In the complex Drâa catchment a DSS has to incorporate regions (a), (b) and (c) based on an efficient hydro-meteorological monitoring system including the infill levels of the reservoir and water use upstream of the reservoir. In region (a), surface water is still more or less an unlimited resource but in (b) and (c) the limiting factor is water for irrigation.

4. INTEGRATION OF SCENARIOS INTO DSS

In order to develop future strategies of water management based on a DSS in the Draa, the development of water management has to be considered. The analysis of hydro-meteorological data in the Drâa catchment of irrigation from groundwater and the Mansour Eddahbi dam is summarized in Figure 4. Before the dam was built, irrigation was mainly dependant on river discharge and groundwater extraction (Figure 4 a). After the dam was built, the palm oases south of Ouarzazate became strongly dependant on dam water use (Figure 4 b). A possible future scenario is shown in Figure 4 c. For a “business-as-usual” scenario, the DSS has to include sustainable water issues such as the rapid capacity loss of dam (20% in only 32 years between 1972 - 2004). If the rapid infill of dam due to high sediment transport rates in rivers continues at the present rate the dam will no longer be fully functional for irrigation as soon as the year 2030. Even now, the dam capacity is insufficient to meet the needs of the downstream consumers during drought and water-shortage conditions. Once the dam reaches a critical silted level (at about half its capacity), it will loose its regulatory flow. Irrigation will be increasingly subject to irregular, flood-dominated flows and will rely more heavily on groundwater resources.

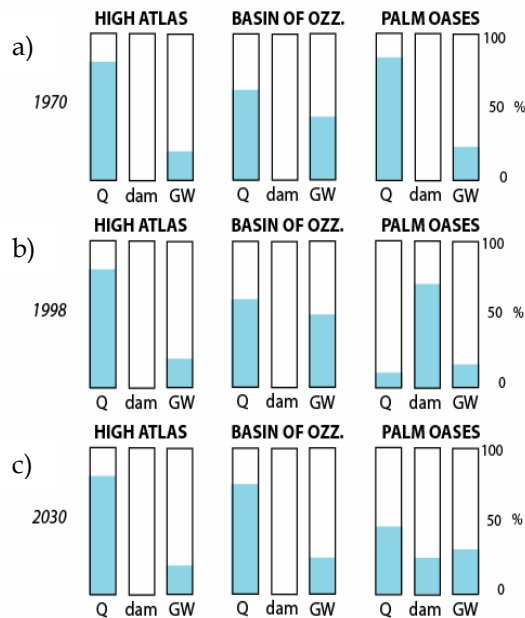


Figure 4 Relative water use in the Drâa for a) pre-dam conditions, b) post-dam conditions and c) future scenario. Q = discharge, dam = Mansour Eddahbi dam, GW = groundwater (based on Direction de la Recherche... and Ministère des Travaux Publics [1998] and Ministère de l'Équipement...[2002]).

However, the dependence on groundwater resources is limited in the southern oases due to high salinity levels. The possible reaction in terms of agricultural water consumption by the local hydraulic agencies, irrigation authorities and local farmers is of utmost importance for the development and long-term implementation of the DSS. In future, the extensive spread of oasis areas at the outlet of the mountain areas has to be controlled, since extensive withdrawal of water in these higher regions can strongly influence the water remaining for irrigation from the dam.

Since water scarcity is a problem that is at the heart of all people across all sectors of the society in the Drâa, a DSS has to be carefully designed. Different stakeholders will have different decision support requirements. In a first step, the priority is therefore put on the decision making authorities. As the DSS is being developed in iterative steps, it will be steered more and more towards smaller water management units (Figure5).

Normally, a DSS will be used by governmental agencies who carry the responsibility of water resources management and planning, e.g. the l'Agence de Bassin (Agadir) and the ORMVAO (Ouarzazate). This in turn implies that the DSS is used multi-laterally with direct participation of end-users (e.g. Irrigation Associations and EAPs). In terms of implementation of the DSS, it is important to learn about the expectations of a DSS from the local stakeholders, such as the irrigation organisations and farming units. It has to be kept in mind that in the Drâa, stakeholders have been confronted with problems of drought and water shortage since decades. For them, a DSS is merely a scientific, computer-based tool that provides a systematic analysis and prognosis of water resources subject to modern, semi-automatic water abstraction techniques. It should be capable of guiding water resources planners to a better management of water in future but it is not expected to take decisions for them. The water planners can simulate a variety of scenarios with the DSS and use it to develop a scenario that wins the approval of as many parties involved as possible. By nature, user conflicts are not avoidable. However, these can be resolved by trade-offs between the principal partners in disposition of a holistic tool that provides scientific support for their decision making.

The mastering of a highly complicated software programme is usually not within the scope of the local irrigation users or mountain inhabitants. As such, the implementation of a DSS by stakeholders in remote regions with high illiteracy rates can be facilitated by running illustrative computer programmes on lab tops in the field

using direct communication techniques with the local stakeholders. The stakeholders could be allowed to identify their fields on the computer and “plant” different crops or augment household water consumption through increasing gîte (bed and breakfast) tourism using differing amounts of water under different scenarios. Thus, a direct and simple output could be explained and discussed at the local scale and the farmers could develop an awareness of the impacts of modern water abstraction techniques.

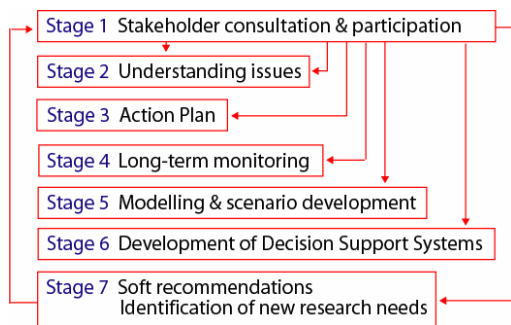


Figure 5 Recommendations for future integrated watershed management

In this context, we have to remind ourselves that integrated watershed management projects are too often coordinated by natural scientists from developed countries that neglect both interaction with social scientists and local end-users. As indicated above, persons that act as an interface between the scientific modellers and resource managers or end-users are essential for the implementation of a DSS. It is important to consult stakeholders from the very initial stages of the project [UNESCO-HELP 2003] to develop a DSS. The vicious cycle in integrated watershed management has to be broken (Figure 5). In the past, projects were geared towards short-term (3-5 years) data collection and data analysis and model results were transferred to the stakeholders only in the final stages. Nowadays (Figure 5) the idea should be to develop action plans with prior stakeholder consultation and participation, including long-term monitoring. The DSS should also be developed from the initial stages in close cooperation with water authorities. Finally, rather than imposing “key-in-the-hand” solutions from the DSS, soft recommendations can be provided on the basis of different scenario outputs for the stakeholders.

5. CONCLUSION

A DSS has to be developed on a sound GIS, hydrological, groundwater and meteorological data base and a flexible, open source hydrological modelling package such as MMS. It should include an intensive monitoring network, including measurement and remote sensing of snow. In terms of scenarios, climate change, in particular droughts, have to be tackled as well as population development and agricultural demand. It has to be taken into account that the implementation of the DSS by potential end-users such as farmers in the mountain areas will not be possible due to high illiteracy rates. However, the interest will be high for centralized agricultural and regional hydrological organisations such as the ORMVAO, related farmers organisations and the Agence du Bassin Hydraulique du Sous-Massa-Drâa as long as a powerful computer infrastructure is available and communication takes place in the French language. The DSS for the Drâa is still in the process of development. It involves close communication with the planning authorities for the development of the irrigation tool and scenarios. As such, the development of the DSS is a continual task for the decades to come and cannot be finalized within the cycle of a single project.

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